Magnetocardiographic mapping: A noninvasive approach to follow up percutaneous transluminal coronary angioplasty results

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1 Introduction

During recent years, percutaneous transluminal coronary angioplasty (PTCA) has developed to the most often applied therapeutical method in coronary artery disease (CAD) even in cases with complex stenosis. Since the beginning of interventional therapy there is need for a noninvasive method to follow up PTCA results, especially because of the number of restenosis mainly in the first six months following PTCA or coronary stenting and the increasing costs and possible side effects of invasive procedures. At present there is no “gold standard” for detecting restenosis, as sensitivity and specificity of noninvasive diagnostical methods in clinical routine for detecting myocardial ischemia like stress tests, nuclear imaging or positrons emission tomography do not allow to clearly identify patients with coronary restenosis after PTCA.[1]

Today magnetocardiography (MCG), as a method of non-contact registration and analysis of the magnetic field of the human heart, seems to be useful as a noninvasive method for detecting CAD. In previous studies MCG proved its high sensitivity to local currents, why it is promising to be an additional method to detect myocardial ischemia. [2; 3]

MCG analysis can be performed using the inverse electrodynamic problem solution, which implies the reconstruction of electrical events in the heart on the basis of registration carried out on the surface of human body.

The detection of so called tangential injury currents was possible on the bases of MCG. Our study aimed to investigate the ability of MCG to detect electrophysiological changes in CAD patients after PTCA using current density reconstruction.

2 Methods

2.1 Patient group

The study included twenty nine patients (mean age 70±6.7, 17 males) with coronarangiographically documented CAD with coronary artery stenosis, defined as a visually estimated lumen narrowing more than 75%, in one or more vessels (12 with one vessel disease, 11 with double vessel disease, 6 with triple vessel disease).

There were twenty one patients without history of myocardial infarction, eight with previous myocardial infarction, four with anterior and five with inferior infarction. One patient was found to have a significant stenosis of an aortocoronary bypass onto the left anterior descendent (LAD).

Twenty patients have been followed up by a third MCG examination one month later.

In comparison, forty-nine healthy volunteers with no history of heart disease, had normal results on physical examination, resting ECG, exercise tolerance test and EchoCG.

2.2 Data acquisition

In all subjects MCG recordings have been performed by means of a one-channel SQUID (super conducting quantum interference device)-magnetometer in an unshielded location. Measurements were done in supine position. Magnetic field registration was carried out on a 6×6 rectangle grid with a 4 cm pitch over precardial area (total area of observation is 20×20 cm). Sensor was located as close to the thorax as possible directly over the heart. Measurements at each point were provided over 30 seconds with simultaneous recording of the reference ECG-channel.

2.3 Data analysis

After averaging all beats at each of the 36 measurement points, equiinductional maps of magnetic field distribution were plotted in course of ST-T interval with 10 ms steps on the bases of two-dimensional interpolation algorithms.

Next the method of magnetic moments (MMM) was applied for inverse problem solution [4]. Briefly this method based on assumption that the sources of measured magnetic field are distributed onto the surface and this surface is located inside the human thorax. Accordingly to used method the surface could be described as a double layer of magnetic charges (instead of the plane of a current density usually used by other approaches). Hence, a double layer of “magnetic charges” is equivalent to the layer of elementary magnetic moments. Inverse problem solution is formulated by an integral equation describing the relation between the unknown “magnetic charges” distribution and the measured magnetic field. As a result, the distribution of the current density (which is equivalent to the “magnetic charges” density) is obtained.

This distribution is displayed in form of current line maps and current density vector maps. Current lines represent curves along that the current flows, i.e. at any point the direction of elementary current is tangential to this line. Current density vectors represent vectors directed tangentially to current lines. Their length is proportional to the value of current density at each point.

These maps were evaluated visually in every patient before and after PTCA and in control group.

We looked for additional areas of relevant current vectors (more than 80 % from maximal vector, red arrows) supposing to reflect the perfusion region of the dilated coronary artery in comparison to the current vector maps of healthy volunteers. We supposed that additional current areas on central and upper part of maps reflect perfusion insufficiency in the region of left anterior descendent (LAD), on the left part in the region of ramus circumflexus (RCX) , on the right part in the region of right coronary artery (RCA). The duration of the presence of these additional areas were compared before and after PTCA in each patient. As the current vector maps were plotted within the ST-T-interval in ten-millisecond steps, which means an amount of at least twenty maps, we have calculated a quantitative index N as the percentage of maps presenting the additional areas.

3 Results

Maps of healthy subjects were characterized by only one area of large current flow vectors and maximal vectors were directed to the left-downwards (sector from 0° to 90°) at the majority of time moments within ST-T interval.

In contrast maps of CAD group showed at least one additional area of current vectors in the perfusion area of the affected coronary artery.

In those maps 24 hours after PTCA in comparison to the maps before PTCA we observed a decrease of duration of current vector areas, localized in the perfusion region of the affected coronary artery, in 13 patients. In 16 patients duration remained the same as before PTCA.

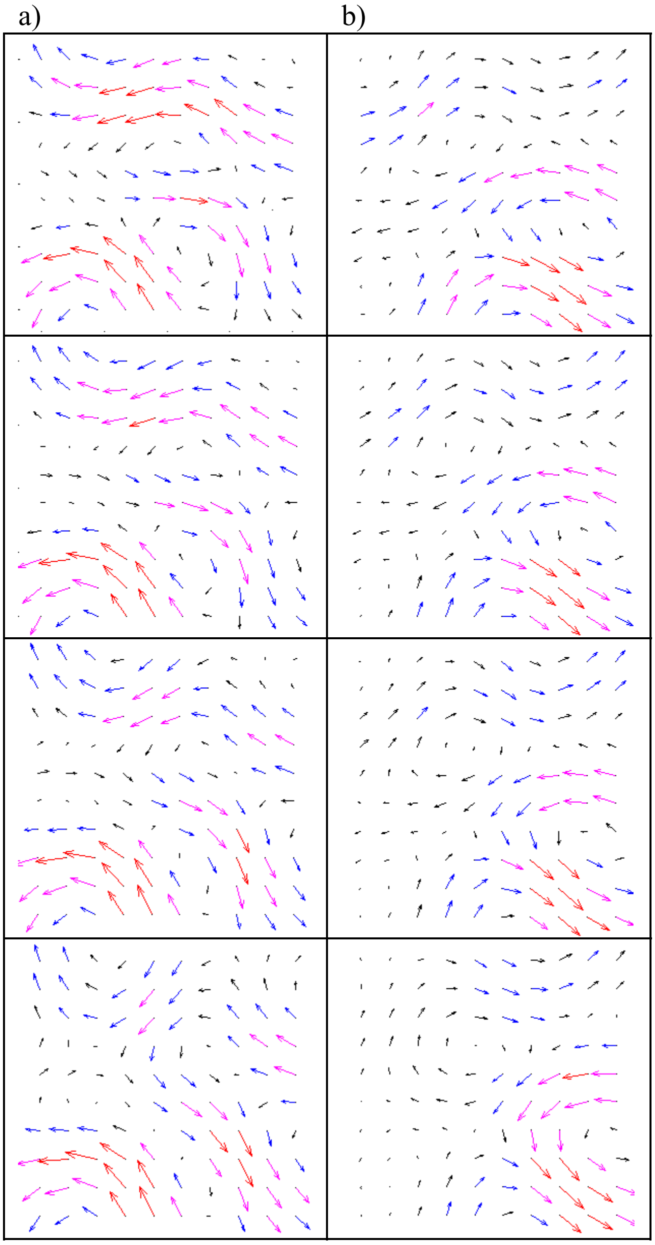

Figure 1: *Current density vectors maps at the middle of the ST-T interval (from 80 ms up to 130 ms after J-point) with 10 mm step of patient JK. a) before PTCA, b) 24 hours after PTCA of RCA.*

In nine out of these cases decrease of duration was observed in a third MCG measurement we worked out one month later.

Examples of the maps of current density vectors before and after PTCA of different coronary arteries are shown in figure 1 to 3.

The index N, used for quantification of duration of the additional area , was 84.1 ± 5.9 before and 53.3 ± 6.7 after PTCA ($p < 0.01$).

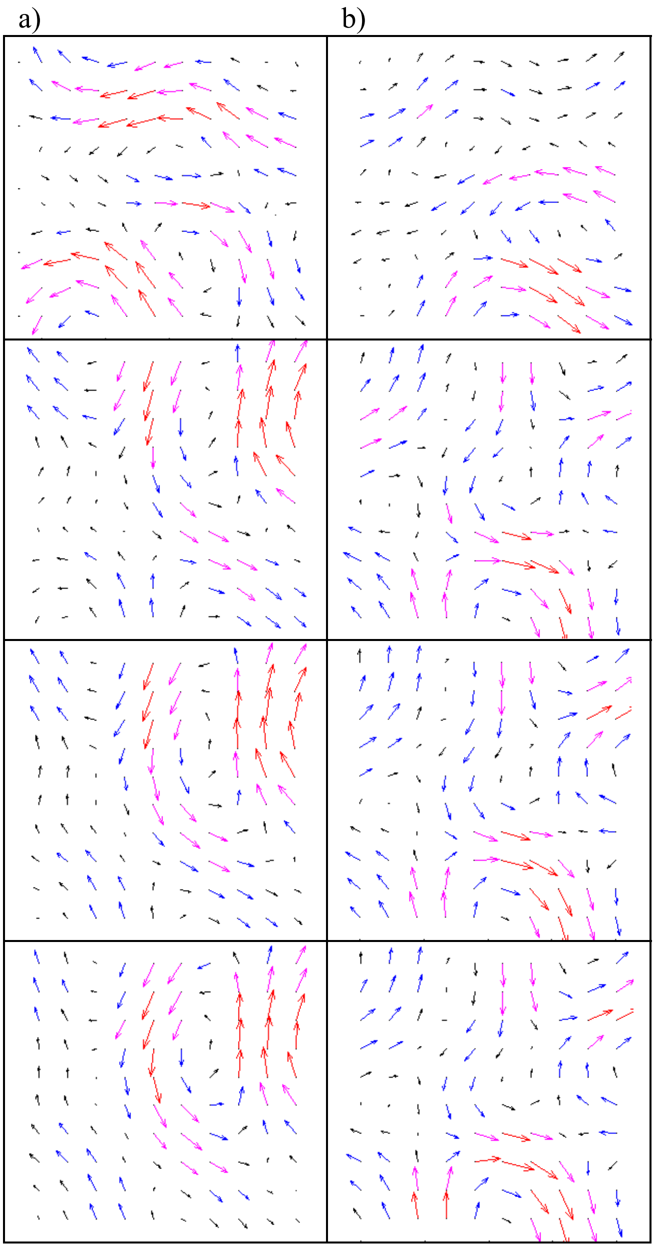

Figure 2**:** *Current density vectors maps at the middle of the ST-T interval (from 80 ms up to 130 ms after J-point) with 10 mm step of patient BT. a) before PTCA, b) 24 hours after PTCA of RCX.*

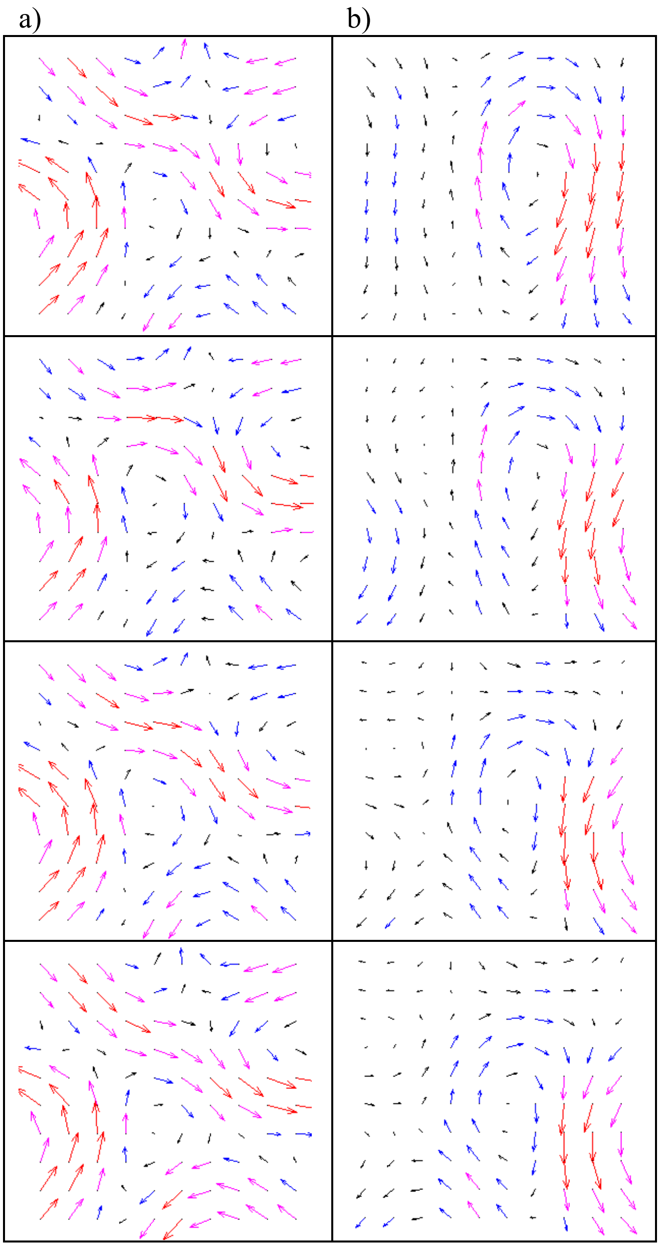

Figure 3**:** *Current density vectors maps at the middle of the ST-T interval (from 80 ms up to 130 ms after J-point) with 10 mm step of patient LH. a) before PTCA, b) 24 hours after PTCA of aortocoronary bypass(LIMA onto left anterior descendent(LAD)).*

4 Discussion

As it was shown earlier MCG is sensitive to electrophysiological disturbances in patients with CAD. Particularly coronary artery disease may alter the spatial dispersion of QT interval at rest. [5]. The results of our study confirmed the potential of MCG to detect changes in coronary blood flow, seen as a intraindividually changed distribution of current density during ventricular repolarisation in patients before and after percutaneous transluminal coronary angioplasty. These changes of current density could reflect, that the inhomogeneity of repolarisation of the myocardial region with insufficient perfusion moves slightly back to be more homogeneous after successfull reperfusion by PTCA. This hypothesis is stressed by the fact, that these changes in current density distribution are more obvious in MCG one month than 24 hours after PTCA. To go even further: if we are able to detect myocardial reperfusion after interventional therapy it will be possible to use MCG for following up PTCA results. Reperfusion is shown by a more homogeneous current density distribution whereas myocardial perfusion insufficiency in the reperfused area is shown by a current density distribution getting more and more inhomogeneous.

However, it remains difficult to combine inverse solution accurately with the anatomy of the heart, particularly, if MCG measurements are not performed at the same day. Nevertheless, as reconstruction of source distribution has shown promising results with useful additional information concerning the electrophysiological activation related to ischemic cardiac diseases in the near past. The clinical usefulness of such methods still remains to be validated in future studies with a larger number of patients to bring magnetocardiography toward routine clinical use for following up PTCA results.

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